

# Circularly Polarized Conical Dielectric Resonator Antenna for X-Band Applications: An Experimental Study

Sounik Kiran Kumar Dash<sup>1</sup>, Taimoor Khan<sup>2</sup>, Mandovi Borthakur<sup>3</sup>

Department of Electronics and Communication Engineering, National Institute of Technology Silchar  
Silchar, Assam, India, 788010

<sup>1</sup>sounikkiran@gmail.com

<sup>2</sup>ktaimoor@gmail.com

<sup>3</sup>mandovi95@yahoo.com

**Abstract**— A wideband (WB) and circularly polarized (CP) antenna is modelled, fabricated, and characterized. The wideband antenna comes with a conical dielectric resonator antenna excited by microstrip fed slot coupling mechanism. In addition to this, a set of tapered sheet is suspended on both sides of the feed line up to the WB slot to ensure circular polarization. From authors' point of view this kind of approach for CP is quite new in this domain. This proposed geometry is modelled with commercial finite element solver HFSS v13.0. The measurement results shows a wide band of 11.46 % (over 7.4 GHz-8.3 GHz) and 5.7 dBi peak gain. In addition to this, a circular polarization (AR < 3 dB) of 4.5% bandwidth is obtained over 7.65 GHz-8 GHz. In view of these results, this model satisfies the basic criteria for X-band wireless applications.

## I. INTRODUCTION

In the era of modern wireless communication, any antennas with improved performances are always appreciated. In view of this dielectric resonator antenna (DRA) is considered to be one of the front liner antenna, because of its advanced characteristics like; wideband, low loss, high efficiency, as well as three dimensional design flexibility than those traditional antennas [1-2]. This antenna was first reported in 1983 [3]. However, from the last decades more attention has been given on improving its performances like gain and circular polarization (CP), etc. [1]. It is a common fact that, as CP systems are insensitive to the orientation of transmitter and receiver, it has numerous applications like Wi-Fi, Wi-Max, X-band (satellite communication), etc. [4]. In view of this, researchers have proposed some techniques but not limited to [6-8], for ensuring circular polarization in different types of DRA. For example; single aperture technique with rectangular DRA [5], quadrature coupler with hollow rectangular DRA [6], parasitic strip with hemispherical DRA [7], conformal strip with elliptical DR [8] has been used for bringing down the axial ratio < 3 dB, warranting circular polarization. Some authors have also used long conductors, like helical conductors in cylindrical DR [9], spiral conductor in rectangular DR [10], etc. for the same purpose.

In here, the authors propose a set of tapered conducting sheet on either side of the feed line to ensure circular polarization in a conical shaped DR. The novelty of this proposal can be noted as; i) use of tapered sheet for CP is

absolutely unique in DRA study, ii) actualization of circular polarization in conical shape DR is probably first time in DRA, iii) < 3 dB axial ratio is obtained between 7.65 GHz-to-8 GHz, iv)  $S_{11} < -10$  dB is observed between 7.4 GHz-to-8.3 GHz with a peak gain of 5.7 dBi. The organization of this paper is as follows; Section II contains the structural overview of the proposed geometry. The design and development is discussed in Section III, followed by measurement and verification in Section IV. Finally the conclusions followed by references are kept in Section V.

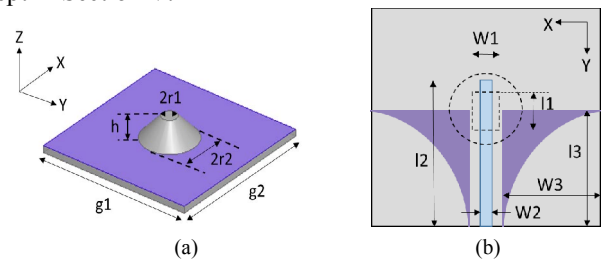


Fig. 1. Configuration of the proposed dielectric resonator antenna. (a) 3D view (b) bottom view. The optimized parameters are:  $g_1 = g_2 = 40$ ,  $r_1 = 2$ ,  $r_2 = 7$ ,  $h = 5$ ,  $l_1 = 7$ ,  $w_1 = 5$ ,  $l_2 = 24$ ,  $w_2 = 2$ ,  $l_3 = 20$ ,  $w_3 = 17$ , thickness of the substrate = 1.6 (All dimensions are in millimeter)

## II. STRUCTURAL OVERVIEW

The proposed dielectric resonator antenna is showed in Fig. 1. It consists of a conical dielectric resonator of upper radius  $r_1 = 2$  mm, lower radius  $r_2 = 7$  mm, and height  $h = 5$  mm having  $\epsilon_{rd} = 10$  ( $\tan \delta = 0.003$ ) placed on a slot of  $l_1 = 7$ ,  $w_1 = 5$  mm. The slot is etched on a ground plane ( $g_1 \times g_2 = 40 \times 40$ ) mm<sup>2</sup> of thickness 1.6 mm and  $\epsilon_{rsub} = 4.4$  ( $\tan \delta = 0.02$ ). This is fed by a single 50 $\Omega$  microstrip line of  $l_2 = 24$  mm,  $w_2 = 2$  mm for suitable coupling [Fig. 1]. A couple of tapered sheet is made on both sides of the feed line with necessary dimensions  $l_3 = 20$  mm and  $w_3 = 17$  mm. This proposed structure is modelled with finite element solver Ansoft HFSS v13.0.

## III. DESIGN AND DEVELOPMENT

The design flow is divided into small stages for ease of understanding and distinguishing. The steps in each stage is described in detail below.

**Stage 1: Optimization of DRA dimensions:**

In the first step of the design flow, the authors place a conical DRA ( $r_1=1$  mm,  $r_2=8$  mm,  $h=5$  mm) over a square slot ( $5 \times 5$ ) mm<sup>2</sup>, fed by a microstrip line ( $24 \times 2$ ) mm<sup>2</sup>. The dimensions of the conical DRA (upper and lower radius, height) are taken as the tuning parameters and the effect of the variation of these parameters on bandwidth and gain are observed. The effect of variation of the upper radius of the conical DRA on resonance frequency shift is shown in Fig 2(a). The figure suggests that resonance matching improves from -18dB to -28dB as the upper radius is varied from (1 mm  $\leq r_1 \leq 3$  mm). Although gain value is not much affected, for the same variation, resonance frequency also shifts from 9.4 GHz to 8.4 GHz in the lower side indicating frequency reconfigurability [Fig 2(a)]. The upper radius is optimized as  $r_1 = 2$  mm to achieve an impedance bandwidth of 6.91% with a peak gain of 4.86dBi. In the same way, lower radius is also varied and is optimized at  $r_2 = 7$  mm for achieving an impedance bandwidth of 7.91% with a peak gain of 5.24 dBi as described in Fig. 2(b). Lastly the height is varied between 4 mm  $\leq h \leq 6$  mm [Fig. 2(c)]. But upon comparison, simulations show better results at  $h = 5$  (i.e. initial value of  $c$  taken during optimization of  $r_1$  and  $r_2$ ), hence height was fixed at 5 mm.

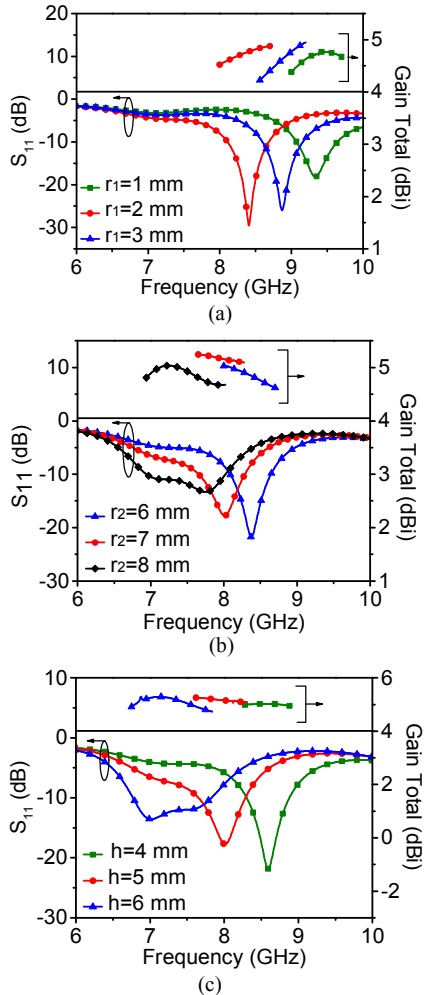


Fig. 2. Parametric study of different dimensions of the conical DRA; (a) upper radius, (b) lower radius, (c) height.

**Stage 2: Optimization of slot dimensions**

At the center, on the top side of the ground plane, a slot ( $l_1 \times w_1$ ) was inserted to couple the DR. The authors conduct a parametric variation of the slot length and width to understand the effects. The length is varied between 6 mm  $\leq l_1 \leq 8$  mm and width is varied between 4 mm  $\leq w_1 \leq 6$  mm with a step size of 1mm. There is negligible effect on the resonance frequency of the antenna [Fig 3 (a), (b)]. Probable outcome of this study interprets that the mode of operation of the DR depends upon its dimensions but not upon the ground plane/slot-dimension [1-3], as the resonant frequency does not vary. The optimized slot length and width was found to be  $l_1 = 7$  mm, and  $w_1 = 5$  mm for an impedance bandwidth of 9.45% with a peak gain of 5.38 dBi.

**Stage 3: Actualization of circular polarization**

Post optimization of DR and slot dimensions, here the authors considers some modification of the ground plane to ensure circular polarization. It can be noted that, though no axial ratio is obtained up to stage-2, impedance bandwidth was (7.56 GHz-8.31 GHz) 9.45 % with 5.38 dBi peak gain.

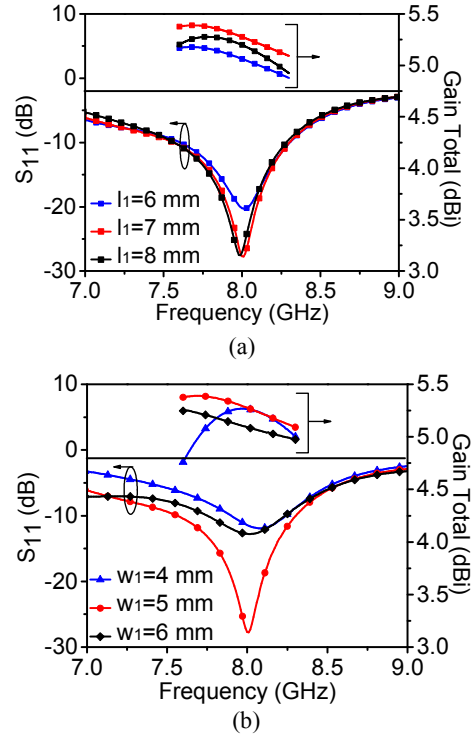


Fig. 3. Parametric study of slot dimensions; (a) slot length, (b) slot width.

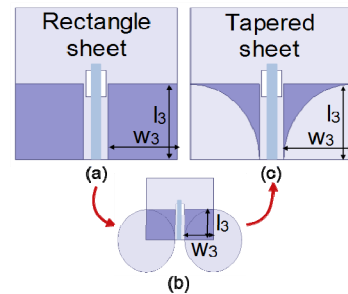


Fig. 4. Development of the modified ground plane.

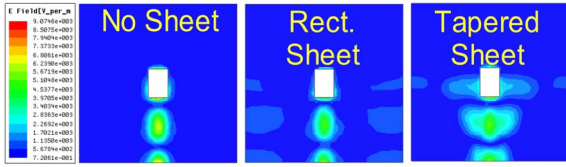


Fig. 5. E-field distribution in ground plane (for different types of sheets).

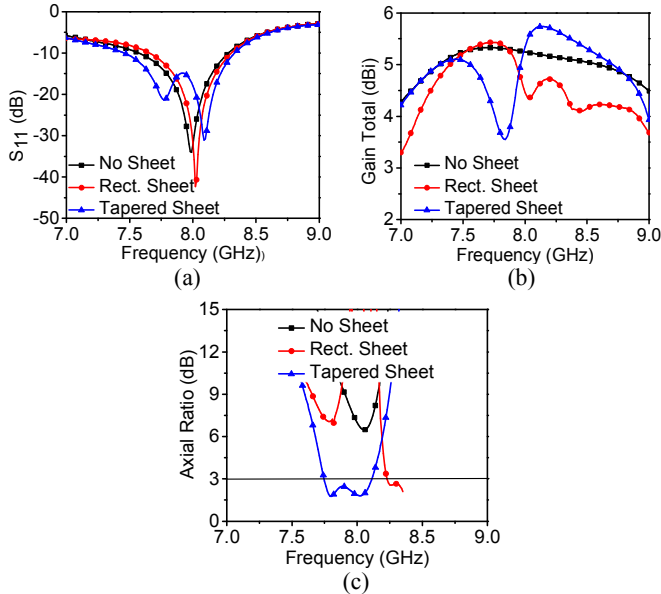


Fig. 6. Parametric study of different sheets; (a)  $S_{11}$ , (b) gain total, (c) axial ratio.

Fig. 4(a) is considered as a modification of Stage-2 along with a set of rectangular patch (each of  $l_3 \times w_3 = 20 \times 17$ ) mm<sup>2</sup> on either sides of the feed line. This is done in order to impose parasitic coupling. As a consequence, E-field becomes stronger than no sheet [Fig. 5]. Thus the bandwidth is 8.02 % (i.e. 7.65 GHz-8.3 GHz) with no effect on the gain of the antenna [Fig. 6]. It can be noted that, no axial ratio is obtained. This indicates that further refinement of parasitic patches is required for circular polarization.

Now, the rectangular patch is modified to a tapered patch. Two ellipses are made each of major axis ( $l_3$ ) = 20mm, minor axis ( $w_3$ ) = 17 mm (i.e. ellipse-1/ellipse-2 [Fig. 4(b)]) and place them at the center of the bottom edge corner of the rectangular patch, such that  $\frac{1}{4}$ th of each ellipse covers some part of the rectangular patch [Fig. 4(b)]. Using subtract tool, these elliptical shapes are subtracted from respective rectangular patches which results in a tapered patch [Fig. 4(c)]. This forms the Tapered sheet. As an impact, the E-field on the top side ground plane along the feed line as well as the tapered patch gets strengthened [Fig. 5]. An additional resonance in the lower frequency is created and bandwidth is enhanced up to 11.28% (over 7.45 GHz-8.34 GHz) [Fig. 6(a)], along with a peak gain of 5.74 dBi [Fig. 6(b)]. Here, we get an advantage of dual resonance occurring at 7.78 GHz and 8.1 GHz. Most importantly, the axial ratio falls below 3dB, ranging 7.75 GHz-8.09 GHz [Fig. 6(c)] ensuring circular polarization, which was the sole objective of Stage 3.

#### IV. MEASUREMENT AND VERIFICATION

Fig. 7 depicts the fabricated prototype. Eccostock HiK material of  $\epsilon_{rd} = 10$  ( $\tan \delta = 0.003$ ) is used to fabricate the optimized DR proposed in Section II. The rectangular slot along with tapered slots on both sides and feed are etched at the respective surfaces of the FR4 sheet ( $\epsilon_r = 4.4$ ,  $\tan \delta = 0.02$ ) using photolithographic etching process. By using adhesive gum the DR is carefully placed over the slot. An automatic anechoic chamber and network analyser are used for characterisation purposes. The comparison of simulated and measured  $S_{11}$  [Fig. 8(a)] shows good agreement. However, the resonance deeps are comparatively less than in the simulated results. The gain total comparative study [Fig. 8(b)] shows good agreement at the lower frequency end with a minor decrease at higher frequency. Similarly, the axial ratio results also show good matching [Fig. 8(c)]. The E-plane ( $\phi=0^\circ$ ) and H-plane ( $\phi=90^\circ$ ) simulated radiation patterns at 7.78 GHz and 8.1 GHz are depicted in Fig. 9, which shows good separation between the co-pol and cross-pol. The comparison summary of all the stages and between the simulated and measured model is shown in Table 1. The observed variation between the simulated and measured results can be owed to the unconsidered deposited soldering material and invisible air gap between the DR and the ground plane sheet.

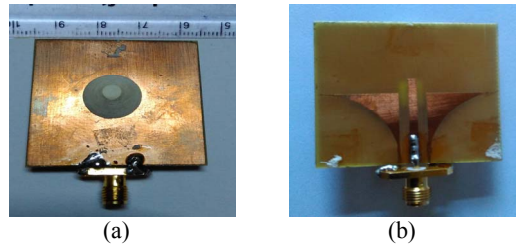
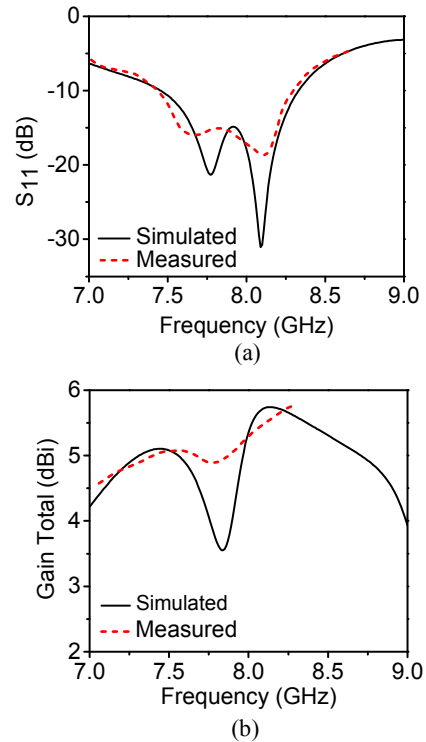
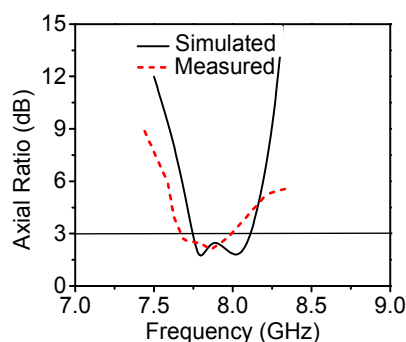


Fig. 7. Fabricated prototype; (a) top view, (b) bottom view.





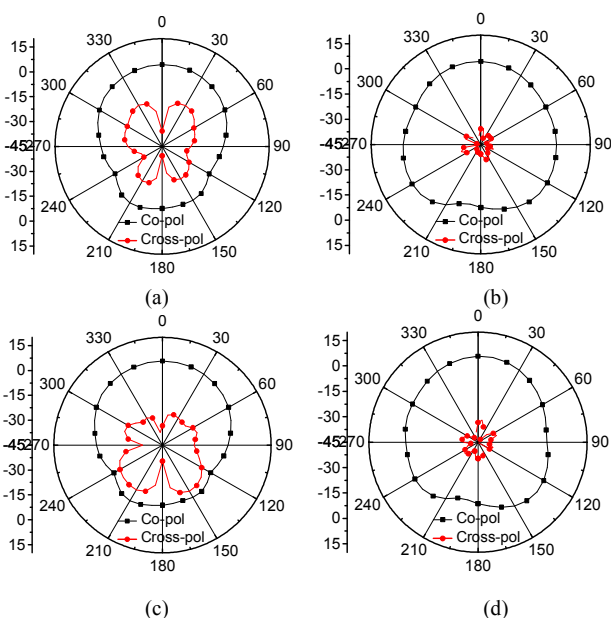
(c)

Fig. 8. Comparison of simulated and measured results; (a)  $S_{11}$ , (b) gain total, (c) axial ratio.

TABLE I

SUMMARY OF ALL STAGES AND COMPARISON OF SIMULATED AND MEASURED RESULTS

Stage	Bandwidth (GHz)	Gain (dBi)	AR BW (GHz)
1	(7.65-8.29)	5.38	NA
2	(7.56-8.31)	5.38	NA
3	Sim. (7.45-8.34)	5.74	(7.74-8.12)
	Mea. (7.4-8.3)	5.7	(7.65-8)



(c)

(d)

Fig. 9. Simulated radiation pattern; (a) E plane, (b) H plane and at 7.78 GHz (c) E plane, (d) H plane at 8.1 GHz.

## V. CONCLUSIONS

A wideband circularly polarized conical shaped dielectric resonator antenna is reported here. A set of tapered sheet is utilized for the first time in DRA in order to exhibit circular polarization as well as dual resonance. During demonstration the antenna operates over 11.46% bandwidth with 5.7 dBi peak gain. The  $< 3$  dB axial ratio was observed between 7.65 GHz and 8 GHz. The measurement and validation of the radiation pattern are in progress. The performance of this model best suits for X-band applications, however proper scope is highly needed for its worthwhile utilization.

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